PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in Waveguide Components

We, GOVERNMENT OF THE UNITED STATES OF AMERICA as represented by the Secretary of the Army of Washington District of Columbia 25, United States of America, do hereby declare the investion, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to microwave structures, and more particularly to copperplated foam dielectric antenna and waveguide components and the method of making the same.

Microwave circuits have broad application in many diverse fields such as, for example, radar and communication systems, missile fuzes, and computer circuitry. The primary disadvantages of these circuits when waveguide components are used are their great weight and high cost of manufacture. The chief factor contributing to excess weight and bulkiness in standard waveguide systems is the use of metal waveguides and flanges with thick walls. Standard microwave systems fabricated from hollow waveguides are generally made from brass or copper alloy tubing with wall thicknesses varying from as much as 0.125 to 0.025 inch, depending upon the application. To reduce the weight, some relief is realized through the use of aluminum and magnesium; however, this adds greatly to the cost of the system. A further reduction in bulk is obtained when the waveguide components are designed in a minimum volume and assembled together as a complete system by machine milling and dip brazing or by investment casting techniques. The method chosen depends largely on the quantity required and the complexity of the system. Many modern radar system antennas and waveguide structures require even greater reductions in mass and increased design flexibility without serious sacrifice in electrical performance. Missile fuze systems ideally require microwave circuits having zero mass and which, as a result, do not obstruct the blast pattern of the warhead.

It is therefore an object of the instant invention to provide microwave antenna and waveguide components which have substantially identical electrical characteristics and greatly reduced masses as compared to conventional components.

It is another object of this invention to provide microwave devices which are mechanically rigid and thermally stable but which are a fraction of the weight of conventional microwave devices.

It is a further object of the invention to provide waveguide components which are extremely lightweight and inexpensive to manufacture, permit great flexibility of design, and may be directly substituted for conventional components in existing waveguide systems.

It is yet another object of the invention to provide a method of manufacturing low cost, lightweight antenna and waveguide components.

According to the present invention, foregoing and other objects are attained by providing microwave components fabricated of metal plated, rigid foam dielectric material having a loss tangent not greater than about 0.006 and a dielectric constant not greater than about 1.7 and a method of electroless copper plating of foam dielectric substrates which have been machined or cast to the internal shape of a conventional microwave component, the thickness of the metal plating being substantially less than that of said conventional air filled microwave component.

The invention, will be further described with reference to the accompanying drawing, in which:

Fig. 1 is a flow diagram illustrating the steps in the manufacture of waveguide anten-

nas and components according to the invention.

Fig. 2 is a perspective view of a typical planar slot antenna array manufactured according to the invention;

Fig. 3 is an exploded perspective view of a slotted waveguide directional coupler manufactured according to the invention;

Fig. 4 is a perspective view of a waveguide component manufactured according to the invention having a flange fabricated on the end thereof to facilitate connection to other flanged waveguide components; and

Fig. 5 is a perspective view of a waveguided component manufactured according to the invention having a coaxial connector soldered onto the broad wall thereof to permit coupling electromagnetic energy into the component from a coaxial line;

In the microwave frequency region, the utilization of the thick wall on standard size waveguide components is essentially only to provide a rigid mechanical support for the transmitting medium, since the current density associated with the propagating wave is concentrated in the waveguide very near the inside wall surface. The depth of the conduction current, i.e. the skin depth, with air as the propagating medium is expressed as follows:

$$\delta = \frac{1}{2\pi}\sqrt{\frac{\lambda\rho}{30\ \mu}}$$

where ρ is the resistivity of the conductor in ohms-cm, μ is the permeability of the conductor, and λ is the free-space wavelength. Typically δ is between 10^{-5} to 10^{-2} cm.

This invention employs low-loss foam dielectric materials having small dielectric constants as the propagating medium rather than air. These materials are rigid and can, as a result, provide support for thin metallic surfaces. Metallic surfaces on the order of five mils in thickness encapsulating the dielectric material are sufficient to carry the rf current. The dielectric materials are actually foams having loss tangents between 0.0001 to 0.006 and dielectric constant values between 1.05 to 1.7. Since these loss tangents and dielectric constants are close to those for air, the dielectric material is shaped, as by milling, or molded to the interior dimensions of a conventional waveguide structure. A thin metallic surface is then applied to the dielectric material, preferably by a plating process to be described hereinafter. The dielectric foams used are extremely lightweight; therefore, the resulting waveguide structures are themselves very light in weight. The usual loss associated with conventional transmission lines, such as copper losses, dielectric losses reflection and impedance mismatches, are also associated with waveguide structures made in accordance with this invention. The magnitude of these losses is controlled by the characteristics of the dielectric, roughness of the surface, and the quality and nature of the plated surface. Variations in density of the dielectric foam material has no adverse effect on the loss and reflection characteristics.

The dielectric foam material may be either organic foam plastics or inorganic foam materials. Organic foams have the advantages of having uniform densities and being easy to fabricate or foam into desired patterns, resulting in very smooth surfaces for plating. The water absorptive properties of organic foams are negligible which permits them to be used in high humidity environments without protection. The chief disadvantages of these materials is that they begin to distort and soften and temperatures above 175°F. Preferred organic dielectric foam materials are expanded polystyrene and polyurethane foam, both of which are available commercially. Expanded polystyrene has a dielectric constant of 1.07, a loss tangent of 4×10^{-4} and a density of 4.3 pounds per cu. ft. Polyurethane foam has a dielectric constant of approximately 1.08, a loss tangent of 1×10^{-3}, and a density of about 2.5 pounds per cu. ft.

Inorganic foam materials are very good for high-temperature applications above 500°F. Although the material density is uniform in inorganic foams, the finished surface resulting from milling or grinding is not as smooth as those obtained using organic plastics. Preferred inorganic foams are a borosilicate low-loss cellular glass sold by Corning Glass Works and identified as 1742 glass foam and silica glass in the form of tiny spheres pressed together. The latter material is obtainable from Emerson E. Cummings Co. as ECCO Foam S_1. The borosilicate low-loss cellular glass has a dielectric constant which is less than 1.5, a loss tangent of 8×10^{-4}, and a density of 0.27 grams per cc. Silica glass foams have dielectric constants of 1.8, loss tangents of 3×10^{-3} and 0.7 grams per cc.

The metallic plating of the dielectric foams is preferably obtained by depositing a film of copper on the foam material by a chemical reduction process of the type generally known as electroless plating. This unique process produces a deposition of metal of a uniform thickness on the preferred foam dielectric materials. Referring now to Figure 1 of the drawings which is a flow diagram of the process, the first step in plating a foam dielectric material which has been previously shaped or formed to the internal configuration of a desired waveguide structure is to deglaze the surfaces of the dielectric material. An abrasive material is generally used for this purpose or in some cases the finished ground surface is acceptable. After deglazing the surfaces of the foam dielectric material

are cleaned to remove all dirt, grit, and foreign matter. In the case of the organic foams a nonsilicated, mildly alkaline cleaner having a PH between 6.5 to 8 is used. A standard acid cleaner such as sulfuric acid and chromic acid is used to clean the surfaces of the inorganic foams. An additional cleaning of the inorganic materials is sometimes required which involves scrubbing with pumice and water to remove small glazed spots, water breaks on the surface, or excess particles that are present even after the preliminary cleaning. This additional cleaning step is illustrated in Figure 1 as connected to the flow diagram by way of a dashed line. After cleaning, both the organic and inorganic foam dielectric materials undergo the same processes for further preparation for plating. The dielectric material is next placed in a solution to neutralize any cleaner on the surface or in the pores of the material that would tend to contaminate the dielectric or the sensitizing agent. A solution of stannous chloride is used as a sensitizer to develop a film of tin on the surfaces of the foam dielectric material. The surfaces of the material are then treated with an activator solution, preferably palladium chloride, that provides the proper prime base for the electroless plating operation. At this point the foam dielectric material is immersed in a electroless copper bath containing Fehling-Formaldehyde solution (copper nitrate, sodium bicarbonate, sodium hydroxide, rochelle salt) where the chemical reduction takes place. The dielectric material is kept in the bath for twenty to forty minutes.

Figure 2 illustrates a two-dimensional waveguide planar antenna array made in accordance with the invention. The copper plated surface 11 is shown as partially cut away to expose the foam dielectric material 12. The antenna itself consists of a number of radiating slots 13 in a planar surface fed from individual waveguide channels 14 that are coupled to auxiliary feed lines and coupling networks connected to primary sources (not shown). The radiating slots 13 may be made by cutting away the copper plating after the plating process with, for example, a milling machine. Preferably, however, the areas where slots are desired are masked prior to the plating process to prevent deposition of copper in these areas. The individual waveguide channels 14 are defined by holes 15. The holes 15 are drilled prior to the plating operation and plated through during the plating operation. As a result, they appear in the dielectric material as a series of closely-spaced metallic posts which act as the narrow sidewalls of the waveguide channels. VSWR characteristics as a function of frequency for both the copper-plated foam antenna array and a conventional aluminum air-filled waveguide antenna array are generally the same. This is also true of the radiation patterns of both antenna arrays. A reduction in weight, however, of almost 9 to 1 was effected in the fabrication of the foam dielectric antenna array as compared with its conventional aluminum counterpart.

Figure 3 illustrates the construction of a waveguide directional coupler. This comprises a first waveguide section 17 consisting of a copper-plated foam dielectric having a rectangular cross-section. The copper-plating is removed or prevented from depositing on an area 18 which extends the full width of one broad wall of the waveguide and along the length thereof a distance equal to the width of the waveguide. A second rectangular waveguide section 19 consisting of a copper-plated foam dielectric having radiating slots 21 in one broad wall thereof is positioned over the unplated area 18 of waveguide section 17 perpendicular to waveguide section 17, and the adjacent metallic edges of the waveguide section 17 and 19 are soldered together. A directional coupler made in this manner can be directly substituted for any conventional air-filled waveguide coupler to effect a great savings in weight and cost of manufacture without any loss of electrical performance.

Obviously, many other microwave devices and components can be made in accordance with the basic teachings of the invention. The waveguide antenna array and directional coupler shown in Figures 2 and 3 are merely illustrative. It is, of course, important to provide means by which microwave components according to the invention may be connected to conventional microwave elements. This is readily accomplished as illustrated in Figures 4 and 5. Figure 4 illustrates a rectangular waveguide section 23 consisting of a copper-plated foam dielectric to which has been attached a flange 24. Flange 24 consists of a copper-plated planar sheet of foam dielectric material through which a rectangular holes has been cut. The dimensions of the rectangular hole correspond to the external cross-sectional dimensions of the waveguide section 23. The waveguide section 23 passes through the rectangular hole in the flange 24 and is soldered to the flange 24 to fix it in place. The flange 24 has holes 25 drilled therethrough in the standard bolt pattern for waveguide components.

Figure 5 illustrates a co-axial connection to a copper-plated foam dielectric microwave structure. The microwave structure 27, which may be of any desired configuration, is here illustrated as a rectangular waveguide section. A standard co-axial connector 28 is attached to the broad wall of structures 27 by drilling a small hole through the structure. The hole has a diameter just sufficient to accommodate without short circuiting the center conductor

of the connector 28 which is passed through the microwave structure 27 and soldered to the underside thereof. The flange of the co-co-axial connector is soldered to the upper copper-plated surface of the microwave structure 27.

WHAT WE CLAIM IS:—

1. A microwave component comprising a rigid foam dielectric material having a loss tangent not greater than about 0.006 and a dielectric constant not greater than about 1.7, said foam dielectric material having a shape and cross-sectional dimensions of the internal air space of a conventional air-filled microwave component, said foam dielectric material further having applied to selected areas of its surfaces a thin metallic plating having a thickness sufficient to support the radio frequency current of an electromagnetic wave propagating through said component but having a thickness substantially less than that of the said conventional air-filled microwave component.

2. A microwave component according to claim 1 wherein said foam dielectric material is an organic plastic foam and said metallic plating is copper.

3. A microwave component according to claim 2 wherein said organic plastic foam is expanded polystyrene.

4. A microwave component according to claim 2 wherein said organic plastic foam material is foam polyurethane.

5. A microwave component according to claim 1 wherein said foam dielectric material is an inorganic foam material and said metallic plating is copper.

6. A microwave component according to claim 5 wherein said inorganic foam material is a borosilicate low-loss cellular glass.

7. A microwave component according to claim 5 wherein said inorganic foam material is a silica glass in the form of tiny spheres pressed together.

8. The method of making a microwave component according to claim 1 comprising the steps of:

(a) shaping a foam dielectric material having a loss tangent not greater than about 0.006 and a dielectric constant not greater than about 1.7 to a configuration and cross-sectional dimensions corresponding to the configuration and cross-sectional dimensions of the internal shape and cross-sectional dimensions of a conventional air-filled microwave structure,

(b) deglazing the surfaces of the shaped foam dielectric material,

(c) cleaning the deglazed surfaces of the foam dielectric material with a cleaner,

(d) neutralizing the cleaner remaining on the surfaces or in the pores of the foam dielectric material,

(e) then treating the surfaces of the foam dielectric material with a sensitizer solution of stannous chloride to develop a film of tin on the surfaces,

(f) treating the sensitized surfaces of the foam dielectric material with an activator solution of palladium chloride to prime the surfaces,

(g) immersing the primed foam dielectric material in an electroless copper bath for a period of between 20 and 40 minutes.

9. Microwave components and methods of making the same substantially as herein described with reference to and as illustrated in the accompanying drawings.

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Agent for the Applicants.

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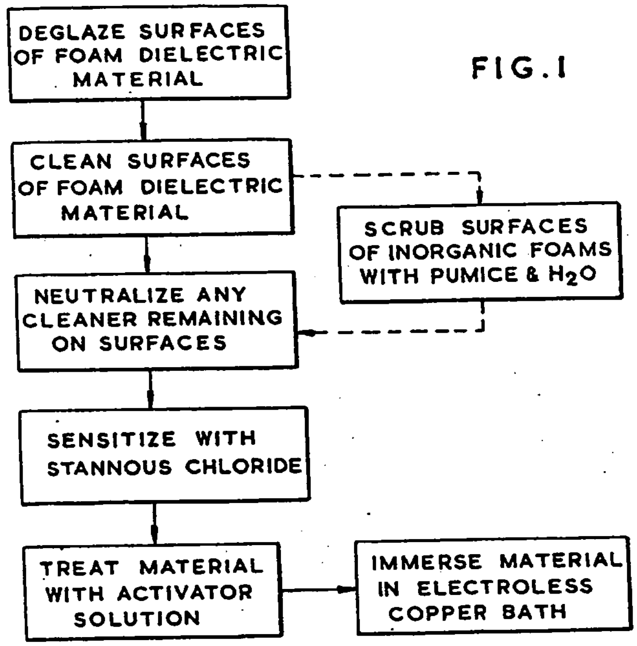
FIG. 1


DEGLAZE SURFACES OF FOAM DIELECTRIC MATERIAL
CLEAN SURFACES OF FOAM DIELECTRIC MATERIAL
SCRUB SURFACES OF INORGANIC FOAMS WITH PUMICE & H_2O
NEUTRALIZE ANY CLEANER REMAINING ON SURFACES
SENSITIZE WITH STANNOUS CHLORIDE
TREAT MATERIAL WITH ACTIVATOR SOLUTION
IMMERSE MATERIAL IN ELECTROLESS COPPER BATH

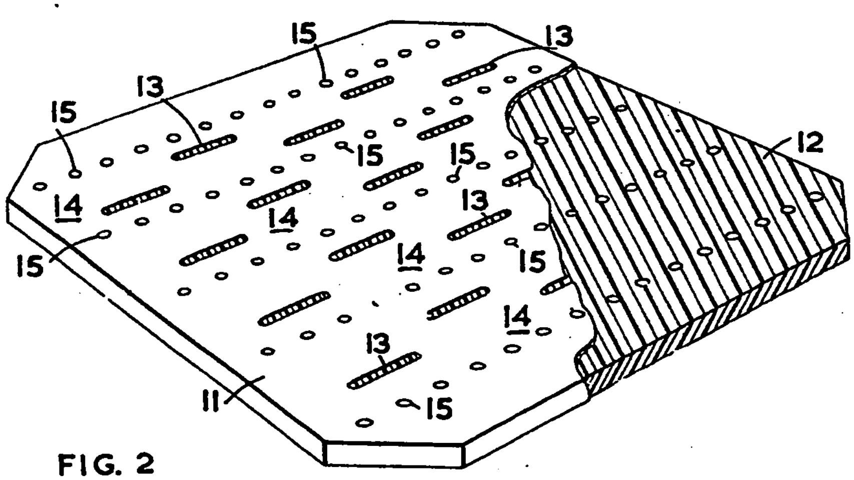

15
13
12
14
11

FIG. 2

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

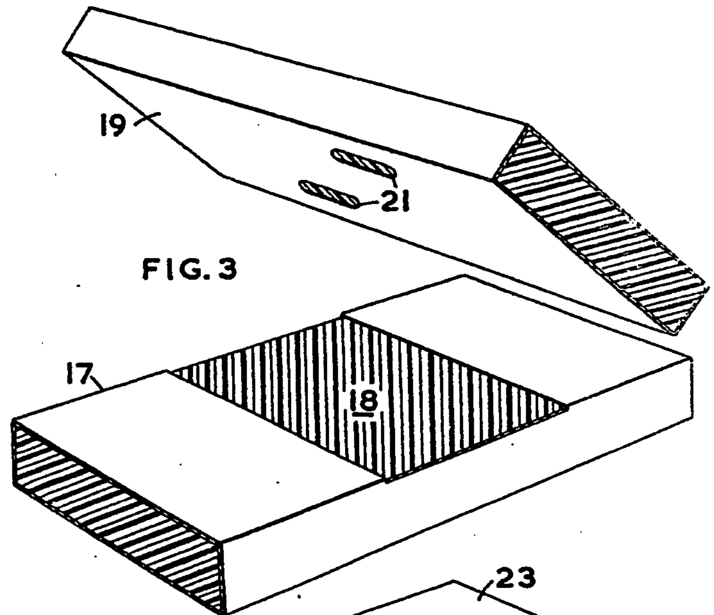

FIG. 3

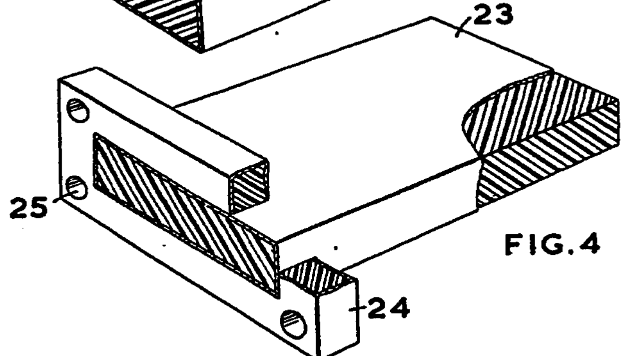

FIG. 4

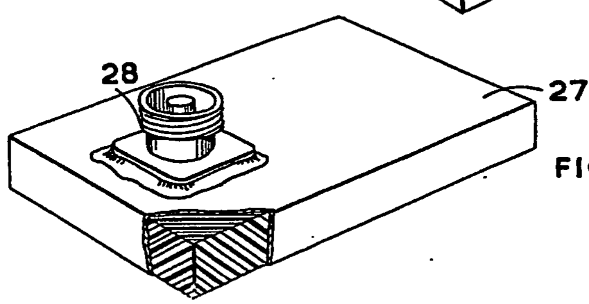

FIG. 5